25 Complications of Percutaneous Lithotripsy

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INTRODUCTION

The first documented percutaneous nephrostomy was performed by Thomas Hillier, MD, in 1865; however, it was not until 1955 when Willard Goodwin published his work on percutaneous nephrostomy for hydronephrosis, that percutaneous nephrostomy gained widespread acceptance (1,2). Goodwin's report provided the foundation for minimally invasive renal surgery. More than 20 years later, Ferstrom described the first planned percutaneous pyelolithotomy (3). Stone extraction required fluoroscopic imaging and endoscopic skill to break and remove renal stones. Since then advances in endoscopic equipment including the fiberoptic light source have helped to make percutaneous access to the kidney, a useful route for almost all renal and ureteral surgery involving the upper collecting system.

ANATOMY REVIEW

In order to prevent complications in percutaneous renal surgery the urologist must understand renal anatomy. Below the skin the latissimus dorsi muscle and the erector spinae muscles overlie the intercostals muscles and ribs. Intercostal vessels and nerves run along the costal groove located on the inferior aspect of each rib. Any intercostal access should be obtained immediately above the rib to avoid damage to the neurovascular elements. The upper pole of the left kidney typically extends to the upper border of the 11th rib at the level of the 12th thoracic vertebrae while the top of the right kidney being pushed down by the liver is usually at the first lumbar vertebrae. Deep to the ribs is the diaphragm, which attaches to the inferior border of the 12th rib. Between the diaphragm and the ribs is the parietal pleura which is reflected to the level of the 10th rib in the mid axillary line and usually crosses the 12th rib at its mid-point, making the lateral half of this rib inferior to the pleural margin. The diaphragm comes down to cover the posterior upper pole portions of both kidneys while the middle and lower poles rest on the psoas and quadratus lumborum. The slope of the psoas muscles causes the lower pole of the kidney to tilt anteriorly, this allows for a straight tract along the long axis of the kidney if the posterior upper pole calyx is used for renal access (4). Between the kidneys and muscles is a layer of pararenal retroperitoneal fat which surrounds the perirenal fascia commonly called Gerota's fascia. Gerota's fascia is made of anterior and posterior leaves, which fuse medially, laterally, and superiorly to enclose perirenal fat, adrenal gland, kidney, and ureter. Inferiorly Gerota's fascia remains open and is contiguous with the retroperitoneal fascia (Fig. 1).

The anterior relation of the left kidney include the left adrenal, spleen, stomach, tail of pancreas, jejunum, and splenic flexure of the colon, whereas the right kidney is in association with the right adrenal, liver, duodenum, and hepatic flexure of the colon.

The typical kidney has seven to nine renal papillae each cupped by a corresponding minor calyx. These calyces are usually arranged in two rows with the posterior calyces opening posteriorly and the anterior calyces opening laterally. These minor calyces narrow to an infundibulum before joining other minor calyces to form a major calyx. Typically three major calyces join to form a single renal pelvis, but there can be great variability in calyceal formation. The renal pelvis may also be bifid which results in a narrower pelvis. Care should be taken when treating a bifid system, as the narrow pelvis does not have the same parenchymal backing of a narrow calyceal infundibulum.

The renal artery and vein are typically anterior to the renal pelvis. The artery normally has four to five branches. The earliest branch is the posterior segmental artery. It is the only branch located posterior to the renal pelvis, making it the most susceptible to injury during percutaneous

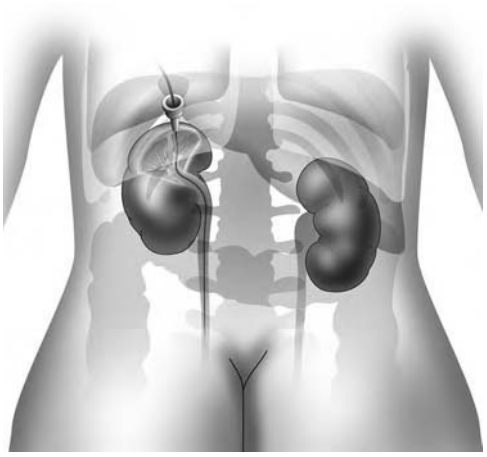

FIGURE 1 Renal anatomy.

procedures, especially when access is too medial. Brödels line is an avascular plane between the anterior and the posterior blood supplies approximately 1 cm from the lateral margin of the kidney on the posterior aspect. When obtaining access to the collecting system a needle path that is posterolateral aimed end-on to a posterior calyx will traverse Brödel's line transparenchymally minimizing risk of injury to major blood vessels (5). The arterial supply of the renal pelvis and ureter also comes from the main renal artery entering from the medial aspect. Any reconstructive surgery should consider the vascular supply, and incisions in the proximal ureter should be made laterally.

Renal anatomical variants are not uncommon, and horseshoe kidney is the most common renal fusion anomaly with an incidence of about 1 in 400 persons worldwide. During development the kidneys fuse at the lower poles and the inferior mesenteric artery halts their ascent. The fusion prevents normal rotation of the kidneys, leaving the renal pelvis anterior and the calyces posterior. The whole vascular supply usually enters medially making injury during percutaneous renal surgery (PRS) and access less likely (6). In horseshoe kidneys upper pole access is favorable, as the upper pole tends to be lower making pleural injury less likely, and their anterior displacement make the shorter upper pole nephrostomy tracts more desirable (Table 1)

PREOPERATIVE IMAGING

Although knowledge of renal anatomy is essential, it is the variations in anatomy that often lead to complications. Therefore, proper imaging is required for preoperative evaluation and surgical planning. Intravenous pyelogram (IVP) is usually sufficient for uncomplicated cases; however, advances in technology and decrease in cost have allowed computed tomography (CT) to be the predominant imaging modality for the upper urinary tract. Although CT offers the

TABLE 1 Indications for Percutaneous Renal Surgery

Percutaneous renal drainage
Whitaker test
Renal cyst aspiration and sclerotherapy
Renal biopsy
Percutaneous nephrostolithotomy
Antegrade endopyelotomy
Percutaneous resection of urothelial cancer
Percutaneous endopyeloplasty
Calyceal diverticulum with or without lithopaxy
Percutaneous infundibuloplasty
Incision or dilation of ureteral stricture
Perfusion chemolysis for nephrolithiasis
Percutaneous cryoablation or radiofrequency ablation

highest sensitivity for identifying renal calculi and masses, due to the axial imaging of CT, some anatomical variants such as a bifid renal pelvis may be more apparent on IVP which images the kidney in the anterior to posterior (AP) view. This can be overcome with the use of three-dimensional reconstructions or coronal slices for CT and magnetic resonance imaging (MRI) as well as coronal slices on MRI. Additionally, CT-urogram as well as MRI urography can be used to enhance evaluation of the collecting system (7).

Preoperative ultrasound can also be used to assess the level of hydronephrosis, and for determining the feasibility of percutaneous access in complicated cases.

Knowledge of the vascular anatomy may be necessary for planning the correction of ureteropelvic junction (UPJ) obstructions, and identifying crossing vessels. CT or MRI angiography can be performed to better, elucidate the renal vasculature. When combined with three-dimensional reconstructions the anatomy becomes easier to interpret (8).

Nuclear imaging studies may be used to determine differential function and assess obstruction. A dimercaptosuccinic acid (DMSA) scan provides percent renal function to assess the prudence of performing renal surgery versus nephrectomy for an impaired kidney (cutoff is generally <20% for adults). Diuretic renography with mercapto acetyl triglycine (MAG3) or diethylene triamine penta-acetic acid (DTPA) can be performed to help determine if a UPJ or ureteral obstruction would benefit from surgical correction.

PREOPERATIVE EVALUATION

Proper preoperative evaluation is the cornerstone to preventing complications. Having accurate knowledge of patient risk factors can allow correction preoperatively and increased caution intra-operatively. The only absolute contraindications to PRS are uncorrected bleeding diathesis, or suspicion of a hydatid fluid collection (9,10). Strong contraindications include active urinary tract infection, and medical comorbidities making patients unfit for surgery (11). Obesity in, and of, itself is not a contraindication for percutaneous surgery; however, modification to the standard technique and equipment may be required, as well as acceptance of higher complication rates in some series (Table 2) (12).

A detailed medical and surgical history along with a physical examination should be performed prior to any procedure. Special attention should be paid to contrast or shellfish allergies, valvular heart disease, surgical implants, respiratory problems, religious beliefs limiting the use of blood transfusions, and prior renal and abdominal surgery. Minimum requirements for preoperative testing include complete blood cell count, coagulation profile including prothrombin time, activated partial thromboplastin time and platelet count, blood urea nitrogen, creatinine, urinalysis, urine culture and blood typing and screening. Chest X ray (CXR) and electrocardiogram should be performed in patients with histories warranting these tests (Table 3).

For elective procedures patient should suspend medications that alter platelet function (e.g., aspirin). Patients with thrombocytopenia should consider correction with platelet transfusion. Patients taking coumadin should have coagulation factors normalized prior to surgery. Although the risk of significant bleeding problems is only 1% to 3%, the possibility of transfusion should be discussed with patients. Routine autologous or designated donor blood is not recommended at our institution.

Active urinary infections should be eradicated with appropriate antibiotic treatment. In patients with indolent or recurrent infections we recommend antibiotic treatment up to 2 weeks prior to PRS to limit the risk of perioperative infections. In patients with infections

TABLE 2 Contraindications to PRS

Absolute
Uncorrected bleeding diathesis
Suspicion of hydatid fluid
Relative
Urinary tract infection
Medical comorbidities precluding appropriate anesthesia
Body habitus

Abbreviation: PRS, percutaneous renal surgery.

TABLE 3 Preoperative Evaluation

History and physical examination
Allergies (contrast, shellfish)
Discussion with patient regarding procedure, risks and alternatives
Review of available imaging
Determine if additional preoperative imaging is necessary
Preoperative clearance: ECG, chest radiograph, specialty consultation if indicated
Laboratory testing: CBC, creatinine, BUN, electrolytes, INR, PTT, urine culture, type and screen

Abbreviations: BUN, blood urea nitrogen; CBC, complete blood count; INR, International Normalized Ratio; PTT, partial thromboplastin time.

associated with urinary obstruction, drainage should be considered prior to complex interventions.

PERCUTANEOUS RENAL ACCESS

Positioning and Anesthesia

General endotracheal intubation is the preferred method of anesthesia for most PRS due to the length of procedure and prone positioning. Shorter procedures may be performed with only epidural anesthesia. If regional anesthesia is utilized, a T-6 vertebral level is required for upper tract instrumentation. Local anesthesia and intravenous sedation has been reported (13).

Ureteral Catheter Placement

Prior to percutaneous access a 5 Fr open-ended catheter can be placed in a retrograde fashion to the level of the UPJ, and left in. This catheter can be used to inject contrast and air into the renal collecting system to define the posterior calyces.

Percutaneous Renal Access

At our institution a team approach is used for PRS. The urologist and uroradiologist discuss and plan the appropriate access route for each case. This is particularly beneficial as the radiologists are familiar with the patient in the rare instance that angiography and embolization is needed.

To briefly review our technique, a radiopaque object and fluoroscopic imaging is used to locate the desired calyx at the level of the skin after a ureteral access catheter has been inserted cystoscopically. An 18 g × 7–15 cm percutaneous entry needle with baseplate is directed into the renal parenchyma on end expiration using biplanar fluoroscopy. To avoid colonic injury percutaneous access should be medial to the posterior axillary line. A 21 g × 15 cm needle is advanced through the percutaneous entry needle to access the calyx. Position can be confirmed with urine aspiration and contrast injection. A 0.018 in wire is then advanced through the 21 g needle guided into the ureter or coiled in the collecting system. The percutaneous entry needle and the 21 g needle are then removed in a "pinch-pull" fashion. An 11 blade is then used to make a small incision in the skin and a 6 Fr access catheter with 4 Fr inner sheath is advanced over the wire using Seldinger technique. When the radiopaque marker for the 4 Fr inner sheath reaches the renal collecting system, the 6 Fr access catheter is advanced forward off of the stiff 4 Fr inner sheath, and the inner sheath is then removed. The 0.018 in wire can then be exchanged for a 0.35 in × 150–180 cm, Teflon-coated stiff guidewire, which is advanced down to the bladder. If there is difficulty directing the wire into the ureter, straight or angled nitinol-coated wires, and angled angiographic catheters can be used to direct the wire into the ureter. After confirmation of the guidewire in the bladder with fluoroscopy the 6 Fr access catheter can be exchanged for a 6.5 Fr × 37 cm introducer catheter, and a second 0.35 in × 150–180 cm, Teflon coated stiff guidewire can be placed and secured to the patient (safety wire).

Tract Dilation

With the patient properly anesthetized the skin incision is lengthened adjacent to the guidewire, and a 30 Fr 12 cm balloon dilator is passed over the guidewire under fluoroscopic guidance

until the radiopaque marker is in the calyx. Proper balloon positioning is critical. Overaggressive balloon placement may tear a narrow calyceal infundibulum or displace a renal stone into the parenchyma or renal pelvis causing collecting system perforation. Alternatively, insufficient depth of balloon placement can lead to partial parenchymal dilation and bleeding. With the balloon in position it is inflated with saline-diluted contrast until the waist has disappeared and the balloon is rigid to touch. Care should be taken not to exceed the burst pressure of the ballon (17 atm for the Nephromax balloon) The 30 Fr nephrostomy sheath is then advanced over the balloon in a corkscrew fashion and the balloon is completely deflated and removed over the guidewire. At our institution balloon dilators are preferred over Teflon fascial dilators. Reported transfusion rates after Teflon fascial dilation range from 16% to 25% compared to balloon dilation 10% to 13% (14,15).

Some urologists have advocated a "Miniperc" procedure using 11 to 15 Fr access sheaths which have shown favorable results in regard to bleeding (16,17). Average estimated blood loss using mini percutaneous nephrostolithotomy has ranged from 25 to 83 cc compared to standard nephrostomy access 800 cc (17–20). The benefit in pediatric cases is clearer with smaller anatomy and instruments; however, indication for use of smaller access sheaths may be limited in adult cases in which PRS is usually reserved for larger stone burden or procedures which require larger instruments. In addition, animal studies have not shown an advantage to using smaller access sheaths based on renal scarring alone (21).

Most surgeons today leave a percutaneous nephrostomy drain following PRS; however, tubeless percutaneous procedures where renal drainage is provided only by an internalized ureteral stent has been described. Complication rates compared with standard PRS were comparable. Tubeless PRS does not appear to increase urinoma or transfusion rates (22).

At our institution a small caliber re-entry malecot percutaneous nephrostomy tube is placed at the end of PRS allowing for a second look nephroscopy postoperatively if necessary for 24 hours. If further surgical intervention is unnecessary the nephrostomy tube is either removed or replaced with a small pigtail nephrostomy tube or a ureteral stent depending on the antegrade drainage from the kidney.

COMPLICATIONS

Pleura

The primary risk of supracostal access for PRS is puncture of pleura and lung. An infracostal approach should be used when possible; however, a supracostal approach is often ideal for upper pole access which may be necessary for treating complex renal calculi and other intrarenal and ureteral pathology. The advantages of accessing the upper pole are direct access to upper pole calyx, UPJ and proximal ureter, good exposure of calyceal contents, and renal pelvis and the ability to operate along the long axis of the kidney allowing for less torque from a rigid nephroscope.

The upper pole of both kidneys lies anterior to the 11th and 12th ribs. Supra-12th rib access is usually transthoracic but extrapleural whereas supra 11th rib access is transthoracic and transpleural. Violation of the parietal pleura is usually clinically insignificant and identification of the inferior border of the lung on fluoroscopy during supracostal access is essential in avoiding injury to the lungs.

Complication rate of a supracostal approach is threefold greater than that of a subcostal approach with reported complication rates of 23% to 100% and 1% to 13% for supra 11th and supra 12th rib respectively (4,23). The risk of pulmonary injury is twofold greater on the right side than on the left-hand side (24).

Subclinical pneumothorax or pleural effusion may be observed with serial chest radiographs; however, signs of respiratory deterioration or increased size of pneumothorax or effusion may require placement of a thoracostomy tube (Fig. 2) (25).

Liver and Spleen

Preoperative imaging may suggest hepatomegaly and splenomagaly which may influence percutaneous access for PRS. A preoperative prone CT can help determine the safety of upper pole access. Rarely US or CT fluoroscopy may be necessary to perform percutaneous access

FIGURE 2 Hydrothorax.

safely. In these cases it may be advisable to perform lower pole access with a combined retrograde approach (26).

Injury to the liver during PRS is unlikely (24). Transhepatic percutaneous access is usually without sequelae, and injury to major intrahepatic vessels after track dilation is the greatest risk. If transhepatic access is diagnosed removal of the percutaneous nephrostomy tube with collecting system decompression using an indwelling ureteral stent and foley catheter drainage minimizes the risk of renobiliary fistula formation. If significant bleeding is encountered, balloon tamponade of the track can temporize bleeding and angiographic embolization can be performed.

Splenic injury is also a rare event during PRS (27). It can lead to significant internal bleeding requiring emergent splenectomy for uncontrollable hemorrhage (28). Suspicion for splenic injury may arise intraoperatively in patients who are hemodynamically unstable with a relatively clear visual field during PRS. Intraoperative abdominal ultrasound or postoperative CT can confirm the diagnosis (29).

Colon

Injury to the colon during PRS is a rare event and is usually due to transcolonic percutaneous renal access. Early detection is the key to successful treatment. Patients at risk for colonic injury include those with prior abdominal surgery where colonic adhesions are more likely and those with a history of constipation or other causes of colonic distension. Colonic injury is more likely on the left hand side (colon more likely to be retrorenal on left), or with lower pole and excessively lateral renal access. Subtle symptoms of colonic injury include fever, leukocytosis, abdominal tenderness, and ileus (30,31). More obvious symptoms include blood per rectum, pneumoperitoneum, and gas or feces from the percutaneous nephrostomy (PCN) tube (31,32).

Intraoperative diagnosis is usually made after injection of contrast reveals colonic enhancement. Delayed diagnosis is usually made on postoperative imaging, either antegrade nephrostogram or CT scan confirming transcolonic passage of the PCN tube.

Once identified, treatment includes triple antibiotic therapy (ampicillin, gentamycin, metronidazole), bowel rest, and separation of the gastrointestinal and urinary tracts. This can be accomplished by draining the colon and then decompressing the renal collecting system with a PCN tube or internal ureteral stent and foley catheter. If the injury is identified intraoperatively the PCN tube can be withdrawn into the lumen of the colon to allow the medial colonic injury to heal (33,34). After imaging studies confirm no renal extravasation the Foley catheter can be removed and the PCN tube is further withdrawn to lie in the pericolonic space to allow for the lateral colonic injury to heal.

Alternatively, if identification of a colonic injury is delayed, the PCN tube should be removed and a penrose drain be placed into the pericolonic space under fluoroscopic guidance (31). The pericolonic drain can then be removed three to seven days later followed by discontinuation of

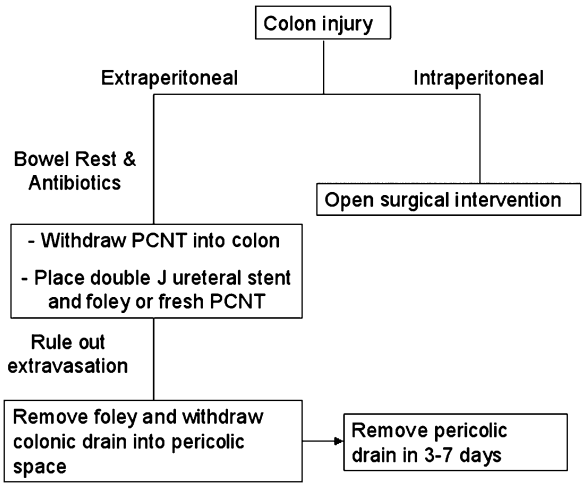
Colon injury
Extraperitoneal
Intraperitoneal
Bowel Rest & Antibiotics
Open surgical intervention
- Withdraw PCNT into colon
- Place double J ureteral stent and foley or fresh PCNT
Rule out extravasation
Remove foley and withdraw colonic drain into pericolic space
Remove pericolic drain in 3-7 days

FIGURE 3 Management of colonic injury.

antibiotics 1 week later. Intraperitoneal colonic perforation or peritonitis warrants open surgical intervention (32). Generally, if a delayed diagnosis of colonic injury is made, a general surgical consult is wise (Fig. 3).

Duodenum and Jejunum

Duodenal and jejunal injury is extremely rare in PRS. Intraoperative diagnosis is by visualization of enteric fluid or enteric mucous membrane folds. Postoperative diagnosis is by CT scan revealing retroperitoneal collection associated with renoduodenal fistula (35). Open surgical repair is the classic approach for duodenal trauma; however, nonoperative management with bowel rest, nasogastric suction, with or without percutaneous duodenal drainage, and renal collecting system drainage has been described (36).

Energy Sources and Equipment Problems—Renal Trauma

Care should be taken when using energy sources. Inadvertent misdirection can result in equipment damaging leading to retained fragments, or renal trauma. In addition, the advent of new energy sources has made aggressive manipulation completely unnecessary in PRS.

A case of a ruptured plastic nephrostomy sheath was reported resulting in significant bleeding requiring transfusion. Stones that do not easily fit into the nephrostomy sheath should be further fragmented (37).

Electrohydraulic (EHL) energy can be used to fragment stones; however, the emitted spark is also capable of damaging the telescope or the collecting system. The EHL probe should always be placed in direct contact with the stone to prevent complications (38).

Ultrasound energy can be used to disintegrate most stones. Continuous flow irrigation helps to cool the tip of the probe; however, when irrigation is held, the tip can become very hot risking injury to endothelium.

Pneumatic lithotripsy can be used in conjunction with ultrasonic energy or on its own. It requires direct contact with the stone and may cause a backward movement of the stone during fragmentation. Use of pneumatic energy should be avoided in delicate tissue.

Laser energy can be used to fragment stones as well as treat renal transitional cell carcinoma (TCC). Although laser penetration depth is shallow, inadvertent laser discharge on endothelium can lead to bleeding making visualization difficult.

Contrast Allergy

Contrast reactions occur in less than 0.2% of PRS. Patients with known contrast allergies can be treated with preoperative steroids. If a reaction develops during a procedure treatment includes antihistamines, H1 and H2 blockers, steroids and epinephrine if needed (39).

Hemorrhage

Bleeding during PRS can occur during needle passage, tract dilation, nephroscopy, or postoperatively. Intraoperative bleeding can usually be limited with the nephrostomy sheath to allow for completion of the procedure. It is important to remember that bleeding from PRS can be brisk and the large instrument diameters and irrigation make underestimation of blood loss more likely.

Renal venous bleeding including renal vein injury is usually treatable with placement and clamping of a large diameter (24–28 Fr) PCN tube to allow for pelvicalyceal tamponade (40). There have been reports of renal vein perforation. A technique described to control this involves inflating a council-tip catheter in the renal pelvis at the site of renal vein perforation and confirming adequate tamponade by the lack of further extravasation of contrast medium into the vein (34,41). The PCN tube should be left in place for two to four days, and removal should be over a guidewire under fluoroscopy to allow for rapid re-insertion should bleeding recur.

Significant arterial bleeding is usually from segmental arteries as the smaller interlobular arteries are surrounded by parenchyma allowing for tamponade. Arterial bleeding can be differentiated from venous bleeding with its brighter color. Unlike venous bleeding, arterial bleeding is more likely to be resistant to conservative treatments. Initial management should control active bleeding with a clamped nephrostomy tube or a tamponade balloon (Kaye—36 Fr, 15 cm). If bleeding persists, angiography and embolization should be performed. Angioembolization is also indicated if bleeding persists postoperatively after replacement of initial blood loss, or if sudden hemorrhage occurs especially if the nephrostomy tube has been removed (Fig. 4) (42).

Late postoperative hemorrhage (after seven days) is most often caused by arteriovenous fistulas or ruptured pseudoaneurysm. Initial management is with angiography and embolization; however, if embolization fails, the next step is partial or total nephrectomy (41,42).

Loss of Material Outside the Urinary Tract

Extrarenal loss of stone fragments may occur with renal pelvis or ureteral perforation, or through the percutaneous access track. In general, loss of stone fragments is not problematic and aggressive attempts to retrieve lost fragments should be avoided (43).

Occasionally fragments can be embedded submucosally within the ureter creating symptomatic obstruction. These fragments tend to be less than 4 mm from the ureteral lumen and often require surgical treatment. Fragments greater than 4 mm from the ureteral lumen tend not to obstruct and do not require further treatment (44).

Retained Material

Retained foreign bodies are usually iatrogenic in nature resulting from broken equipment. Foreign bodies should be removed to prevent infection, granulomatous reaction, or stone formation. If discovered after PCN tube removal, initial attempts at retrieval should be made

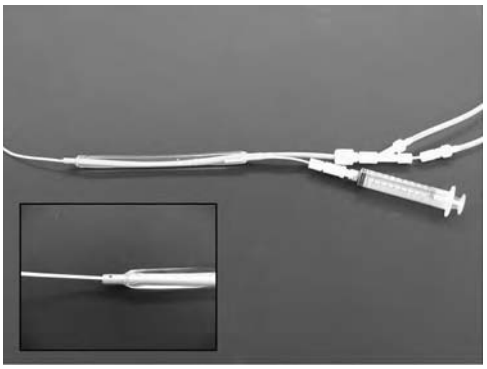

FIGURE 4 Kaye tamponade balloon.

with ureteroscopy. If discovered prior to PCN tube removal a second look nephrostomy can be performed. This procedure is well tolerated without anesthesia and involves flexible nephroscopy through the established nephrostomy track after a guidewire has been placed down to the bladder. Nitinol baskets or flexible graspers can be used to remove foreign body or residual stone fragments. Replacement of the PCN tube is often unnecessary, and if concern for drainage persists, an indwelling ureteral stent can be placed antegrade.

Stricture

UPJ obstruction is a rare complication of PRS (28,45,46). Trauma with or without retained stone fragments is the reported etiology (47). If there is question of a UPJ obstruction an antegrade nephrostogram can be obtained at the time of PCN tube removal. If drainage is delayed a small diameter loop PCN tube is left in place for two to three weeks to allow for possible postoperative edema to resolve. This can be followed by a Whitaker test to confirm obstruction.

Complete distal ureteral obstruction unrelated to ureteral calculi has been reported, following PRS with resolution after prolonged percutaneous drainage (48).

Infundibular stricture is another rare complication of PRS (49). Diagnosis is usually made by imaging revealing calyceal dilation behind the infundibulum with possible urinoma. Treatment involves percutaneous drainage of the infected calyx and retrograde or antegrade infundibulotomy.

Fistulas

Renocutaneous fistula is a rare complication following PRS. Risk factors include prolonged percutaneous drainage, untreated urinary tract infection, ureteral obstruction, radiation history, and poor nutrition status. Diagnosis is suspected with persistent drainage from the nephrostomy track and confirmed by imaging or checking drainage creatinine level. The initial treatment consists of antibiotics and decompressing the renal collecting system with an indwelling stent and foley catheter drainage. If a urinoma is present this should be drained percutaneously. Surgical intervention may be warranted if nonoperative measures fail to heal the fistula. In cases associated with TCC a biopsy should be considered.

The incidence of nephropleural fistula after supracostal access has been as high as 2.3% above the 12th rib and 6.3% above the 11th rib (25). Postoperative chest pain or shortness of breath after PRS through a supracostal approach should raise suspicion for nephropleural fistulas. Retrograde pyelography with confirmation of a fistulus tract is diagnostic, and treatment is usually conservative with renal collecting system decompression and a thoracostomy tube placed on suction initially. Thoracostomy tube can be removed after resolution of effusion or pneumothorax off suction. Persistent fistulas or loculated effusions may require thoracoscopy with decortication and possible sclerosis. Early consultation with a thoracic surgeon is recommended.

Nephrocolonic fistula and colocutaneous fistula are also rare complications of PRS (50). Initial treatment mirrors that of colonic injury during PRS including bowel rest, antibiotics, renal decompression, and colonic drainage. Indolent cases may require surgical intervention.

MEDICAL COMPLICATIONS

Infection and Urosepsis

Preoperative urinalysis and culture are necessary to rule out urinary tract infection prior to elective PRS. If infection is suspected the patient should be treated with a course of antibiotics prior to surgery, and the procedure is deferred until sterile urine is achieved.

Prevention of infection involves administering periopertive antibiotics, low-pressure irrigation, and postoperative renal drainage when appropriate. In patients whose preoperative urine cultures are sterile, single dose aminoglycoside or fluoroquinolones are recommended for routine antibiotic prophylaxis (51). For patients at high risk of endocarditis antibiotic combinations active against streptococci and enterococci are recommended (ampicillin 2.0 g plus gentamicin 1.5 mg/kg within 30 minutes preoperatively, ampicillin 1.0 g 6 hours later. Substitute vancomycin 1.0 g for ampicillin in patients with penicillin allergies) (52). Special

considerations should also be made for patients who have compromised immune systems or patients with prosthetic devices (53,54).

Patients with negative urine cultures preoperatively who are maintained on perioperative antibiotics do not necessarily require immediate bacteriologic evaluation if hemodynamically stable (55). Patients who experience fever, tachycardia, tachypnea, or leukocytocis should be monitored closely and may benefit from perioperative antibiotics. Complicated patients including those with compromised immune systems, history of recurrent infections, ureteral obstruction, retained infection stone fragments, urinary extravasation, or positive cultures from the upper tract should receive postoperative antibiotics. The incidence of urosepsis after PRS is 1% to 2%. Patients with infected urine from the renal pelvis or infected renal stones are at a fourfold greater risk for developing urosepsis (56). Treatment of urosepsis includes renal decompression, aggressive fluid resuscitation, invasive monitoring in an intensive care setting, and broad-spectrum antibiotics. Cultures obtained from the upper tract are superior to voided urine for guiding antibiotic therapy (56).

Intravascular Fluid Overload

Intravascular fluid overload is uncommon during PRS. Risk factors include vascular perforation, prolonged operative times, use of hypotonic solutions, high-pressure irrigation, medical comorbidities including patients with congestive heart failure and chronic renal insufficiency. The key to avoiding this complication is understanding the risks and practicing good surgical techniques. Treatment should start with diuretics.

Extravasation of Fluid

Fluid extravasation following PRS may occur when a shallow access sheath becomes dislodged from the renal collecting system. Extravasation can also occur following injury to the renal collecting system. The management of extravasation usually involves percutaneous renal drainage postoperatively. If a significant amount of fluid is noted intra-operatively it is possible to drain the fluid using the nephroscope perirenally, however caution must be exercised to protect renal access in the form of the safety wire. Postoperative identification of a urinoma can be followed by ultrasound and may warrant percutaneous drainage.

Air Embolism

Incremental injections of 5 to 7 cc of air into the renal collecting system via a ureteral catheter can help delineate the posterior calyces for precise nephrostomy access. Although the normal collecting system has a capacity of approximately 10 cc, air embolism secondary to positive pressure air pyelograms have been reported both before and after initial attempts at calyceal access (57,58). Signs suggesting air embolism include oxygen desaturation, decreased end-tidal carbon dioxide, hypotension, and bradycardia. When air embolism is suspected the procedure should be halted and any routes for further air entry should be sealed. The patient should be placed supine in trendelenburg position and if possible with the right side up. Cardiopulmonary resuscitation should be initiated. A right internal jugular central line may confirm diagnosis with aspiration of foamy blood and be used to evacuate air from the right atrium.

Deep Venous Thrombosis and Pulmonary Embolism

The incidence of venous thromboembolism in percutaneous renal surgery is <1% to 3% (Table 4) (51,59,60). Prevention starts with identification of patients at risk. For uncomplicated patients early postoperative mobilization is probably all that is necessary. For patients at higher risk including those with advanced age and malignancy, graduated elastic stockings and intermittent pneumatic compression stockings may be warranted (61). Routine prophylaxis with low-dose unfractionated heparin or low molecular weight heparin is not indicated and may increase the risk of hemorrhage.

If deep vein thrombosis is diagnosed postoperatively, management is directed at preventing a thromboembolic event. Standard therapy with anticoagulation immediately after surgery may result in bleeding which can lead to further complications. Placement of a vena

TABLE 4 Complications from Percutaneous Renal Surgery

Complication	%
Overall complication rate	4–8
Fever	23–25
Bleeding requiring transfusion	2.3–23
Extravasation	1–7
Transient ureteral obstruction	6
Hydro/hemothorax	<1–2.1
Infundibular stenosis	2
Sepsis	<1–1.25
Pneumothorax	<1
Urinoma	<1
Contrast allergy	<1
Bowel perforation	<1
Renal pelvic laceration	<1
Ureteral avulsion	<1
Ureteropelvic junction or ureteral stricture	<1
Nephropleural or nephrocutaneous fistula	<1
Deep venous thrombosis with or without pulmonary embolus	<1

caval filter can prevent major thromboembolic complications until the nephrostomy track has had time to heal. When anticoagulation is started, monitoring for bleeding should be continued until the patient is stable at therapeutic doses.

Management of acute pulmonary embolism (PE) in the early postoperative period is a challenge as early anticoagulation and thrombolytic therapy for massive PE may be lifesaving. Careful monitoring for bleeding in an intensive care setting is warranted.

Radiation Exposure

Urologists are routinely exposed to radiation during endoscopic cases. Percutaneous nephrolithotomy has the highest radiation exposure to urologists, up to ten times the fluoroscopy time (62). Most of the radiation received by the surgeon comes from scatter from the patient. The radiation dose to the surgeon's legs is usually the highest and increases with closer proximity to the beam. Studies have shown that the estimated annual radiation exposure for urologists is well below the threshold dose for deterministic effects of ionizing radiation (62). Regardless, the as low as reasonably achievable (ALARA) principle should be used when operating fluoroscopy. Minimizing radiation exposure involves wearing lead aprons, thyroid shields and lead impregnated glasses, minimizing fluoroscopy time, collimating the beam (to narrow the field), keeping the image intensifier close to the patient, and keeping the surgeon's hands outside of the beam.

CONCLUSION

Percutaneous renal surgery remains an integral part of the endourologists' armamentarium. It remains the gold standard approach for staghorn stones and calyceal diverticular disease, while its use in the treatment of UPJ obstruction and transitional cell carcinoma continue to expand with the advent of new technology. PRS has also expanded to include the treatment of renal cell carcinoma with ablative therapies. Although percutaneous access is a relatively safe route for renal surgery, awareness for potential complications will lead to early detection and treatment, which is the cornerstone of successful postoperative management.

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